low Energy COnsumption NETworks

ANNEX II OF THE DELIVERABLE D6.5

ECONET IMPACT AND GUIDELINES FOR EXPLOITATION

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1 Potential Impact

In terms of potential impact, ECONET has set a systematic approach to energy efficiency in wired networks, by clearly decoupling the set of HW technologies that constitute the power-consuming elements in the network and their logical abstractions at various levels. At the same time, it has highlighted the relevance of taking into consideration all layers in the Data Plane protocol stacks and their interaction with the Control Plane, in order to understand their relation in the constant trade-off between energy consumption and QoS/QoE.

With reference to the original ECONET vision, the project has achieved, in terms of both design and implementation:

- Local control and optimization of networking devices, obtained on the basis of LCPs specifically designed to address parts of the device. In most cases, the techniques developed exploit the power of virtualization and of the representation – quite usual in networking – of physical resources in terms of their logical abstractions, as ports, virtual links, virtual paths, and the like. While allowing the designer of LCPs to represent the controlled objects and actions in general terms, this vision does not prevent the capability of relating such objects and actions to the power consumption of the HW over which they reside, in order to cope with the "new dimension" in the optimization process introduced by the energy issue. The LCPs that have been developed are in the category of Dynamic Adaptation techniques, and exploit both LPI and AR control capabilities, on the basis of knowledge of the traffic load. Among other aspects, they can act on the links (by adaptively and transparently adjusting the number of active interfaces in bundle links), or on the packet processing engines in line cards (by optimizing the active and idle energy-aware states, the number of active cores, and the load balancing operations). In most cases, the general philosophy behind these approaches is that of adaptively adjusting the power- and QoS-related parameters as functions of the traffic load measured over time windows of the order of minutes or tens of minutes, to cope with slow variations, as exhibited by night and day profiles. Obviously, this approach does not prevent the application of control techniques capable of reacting to fast dynamics in the traffic flow, which, however, should be based on other closed-loop control methodologies, which were not considered in detail in the project (fast reactions are much more related to short-scale QoS maintenance than to energy efficiency).
- A set of NCPs, implementing energy-aware routing and Traffic Engineering methodologies. Besides developing some novel algorithms, both distributed and centralized, the realization of these strategies has required the "green extension" of classical protocols. Moreover, the interaction between LCPs and NCPs, in coordinated hierarchical fashion, has been made possible by the introduction of the GAL architectural concept and interface.
- The definition, implementation and standardization of the GAL, whose aim has been twofold: i) to expose the energy-aware capabilities at different levels of the devices' structural organization and toward the external protocols implementing NCPs in the Control Plane; ii) to hide the details of the hardware/firmware/software proprietary solutions, by defining a set of standard energy-aware states, along with their significant properties and attributes.
- The full development and implementation of the main concepts behind the Network Connectivity Proxy. Though this idea is not new, having been proposed by other researchers in the past, the ECONET consortium has given a substantial contribution to its introduction as a mature technology and to proving its feasibility and effectiveness.

- The implementation of a test bed that contained quite a few of the proposed solutions and techniques, whose measurement data have been extended to a real scale by means of a carefully tuned model.

All these realizations, their implementation results and their performance analyses are available to stakeholders in the scientific and industrial communities, including research institutions, manufacturers and operators. A summary of the main results of experiments and forecasts of the impact in terms of energy saving (in percentage and absolute values), along with a set of guidelines to foster their achievement, is reported in the Annex to this document, with reference to a real telecom operator.

2 Guidelines for a roadmap toward a greener networking environment in the fixed network infrastructure

The main question that arises at this point – after the investigation of the ECONET project has been completed, a bulk of technologies have been developed and analysed, experimental results have confirmed the expectations in a laboratory environment and have been projected onto real network evolutionary scenarios – is how these result should be applied by stakeholders, in order to maximize their potential impact and benefit on the reduction of energy and OPEX, with a reasonable pace that would make the initial CAPEX acceptable.

While a detailed answer to this question could only be provided by focusing on each specific situation of manufacturers and operators, with reference to their individual exploitation plan, nevertheless we can attempt to provide some general guidelines that might be followed as a starting point to shape a development strategy. As the goals of individual policies may be different for operators, manufacturers and regulatory bodies, we distinguish among them in the following.

1.1 Operators

1. As could be expected and as was evidently confirmed by the results of our investigation, areas of the network were the sheer number of devices is larger have the potential to provide a larger gain in energy efficiency in absolute terms. In this respect, access and metro/transport networks should be a major concern of operators, as they can be the sources of a large OPEX reduction. While it is true that most of the access network will be wireless – which was not part of our coverage – nevertheless we can include the wireless backhaul segment of the fixed network in our considerations. Notwithstanding the desirable diffusion of Energy Efficient Ethernet, whose benefits would appear first in data centres, many device-level optimizations that we have seen can be introduced here even on legacy hardware, for instance by making a more aggressive use of layer 2 virtualization in switches and line cards, and by selectively putting DSLAM ports to sleep in the presence of no activity (though the latter action would gradually reduce its impact as the penetration level of FTTC and VDSL increases). As operators are shifting their interest toward the access segment regarding the introduction of SDN and NFV for flexibility and programmability reasons that would easy the creation and offer of new services and decrease their time-to-market, energy efficiency should not be neglected.
2. Even though the home network itself may not be a concern for the operator, there are potentially high indirect benefits stemming from the adoption of smart sleeping techniques in the home segment. Apart from the already mentioned advantage on DSLAM ports enabled by sleeping Home Gateways (HG), the Network Connectivity Proxy (NCP) can allow the

operator offering selective connectivity services to the user, which would foster the adoption of the concept on one hand, and share the gain in the users' energy consumption reduction. The latter may be tiny for the single user HG and devices, but its operator's share would be far from negligible, owing to the numerousness of HG to interact with. Operators may greatly benefit by actions in this segment, considering also the growing relevance of the Internet of Things, Smart Grid and Smart Cities.

3. The introduction of dynamic adaptation techniques in the core network has certainly a smaller absolute impact. Nonetheless, it can be combined with energy-aware routing and traffic engineering techniques, whose potential in overall energy reduction has been estimated in the order of 20%. As such, action in this segment, combined with the overall network optimization, would also yield non-negligible advantages.

1.2 Manufacturers

1. In many cases, it is true that simply exposing the gains attainable through the use of "green" equipment may not be a convincing argument to have one's offer preferable with respect to a competitor. There are a number of features in the characterization of a device or a network that may exhibit more fundamental market relevance (e.g., easiness of management, OAM, flexibility of configuration, assistance, etc.) at a given price. However, should the request from operators become sensible, owing to regulatory policies, environment-friendly attitude, and significant influence of reduced energy expenditures, manufacturers that were not ready to respond would risk losing a competitive advantage. It is therefore highly advisable to plan in time for the introduction of energy-efficiency in new products, and even to invest in green management strategies that can be easily adopted in the presence of legacy hardware.
2. Here again, the recent growing interest in SDN and NFV can be exploited as an opportunity to introduce more energy efficiency into the network, by means of the increased flexibility, control capability and use of virtualization techniques.
3. Energy efficiency introduces a new dimension in network planning, control and optimization, and OAM. Maintaining the trade-off between energy consumption and QoS/QoE forces network engineers to reconsider criteria primarily based on over-dimensioning and rediscover and revisit traffic engineering (NCPs) and local optimizations (LCPs) that would have been once deemed unnecessarily sophisticated and complex. This new aspect opens up the way for creative thought that can generate competitive advancements and solutions even in those countries where software design and system integration are the main activities in the ICT market.

1.3 Regulatory bodies

1. The importance of initiatives like the JRC Code of Conduct cannot be underestimated, as work in regulatory institutions such as this can greatly influence the push on manufacturers and operators and, in turn, steer the users' behaviour. It is highly recommended for all interested stakeholders to participate and bring their vision on network energy efficiency.
2. Standardization bodies play an equally important role. Certainly, one of the lessons learned during the ECONET lifetime is that the coordinated effort of research institutions, manufacturers and operators can pay off in terms of creating effective standard proposals and reducing their time of discussion and approval. The success of the GAL, which we consider a fundamental element to ease the introduction of green networking strategies, is an indication of this possibility and an encouragement to continue along this line.